Paper

EXPOSURE OF THE SWISS POPULATION BY RADIODIAGNOSTICS: 2003 REVIEW

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Abstract—**A nationwide investigation was conducted in Switzerland to establish the exposure of the population by medical x rays and update the results of the 1998 survey. Both the frequency and the dose variations were studied in order to determine the change in the collective dose. The frequency study addressed 206 general practitioners (GPs), 30 hospitals, and 10 private radiology institutes. Except for the latter, the response rate was very satisfactory. The dose study relied on the assessment of the speed class of the screen-film combinations used by the GPs as well as the results of two separate studies dedicated to fluoroscopy and CT. The investigation showed that the total number of all medical x-ray examinations performed by GPs registered a 1% decrease between 1998 and 2003, and that the sensitivities of the film-screen combinations registered a shift towards higher values, leading to a reduction of the dose delivered by a GP of the order of 20%. The study indicated also that the total number of all x-ray examinations performed in hospitals increased by 4%, with a slight increase of radiographies by 1% but significant decrease of examinations involving fluoroscopy (39%), and a 70% increase for CT examinations. Concerning the doses, the investigation of a selection of examinations involving fluoroscopy showed a significant increase of the kerma-area product (KAP) per procedure. For CT the study showed an increase of the dose-length product (DLP) per procedure for skull and abdomen examinations, and a decrease for chest examination. Both changes in the frequency and the effective dose per examination led to a 20% increase in the total collective dose. Health Phys. 92(5):442–448; 2007**

Key words: diagnostic imaging; diagnostic radiology; dose assessment; dose equivalent

INTRODUCTION

THE AVERAGE dose to the population from medical exposure in industrialized countries represents the highest contribution of man-made irradiation. This fact has motivated a great number of studies internationally, during the past decades, aiming at establishing the frequencies of the different types of examinations as well as the associated radiation doses. The United Nations Scientific Committee on the Effects of Atomic Radiation issues regularly a thorough report on the national surveys dealing with medical irradiation published all over the world (UNSCEAR 2000).

In the past, several nationwide surveys were organized in Switzerland in order to investigate the exposure of the population by diagnostic and interventional radiology (Zuppinger et al. 1961; Poretti et al. 1971; Mini and Poretti 1984; Mini 1992). The most recent one took place in 1998 (Aroua et al. 2002a and b) and covered more than 250 types of x-ray examinations from the various modalities in diagnostic radiology, including conventional radiography, angiography, fluoroscopy, computed tomography (CT), mammography, bone densitometry, conventional tomography and dental radiology, as well as interventional radiology. The 1998 study addressed all the institutions that perform x-ray examinations in Switzerland: university and non university hospitals, general and specialized practitioners, dentists, chiropractors, and other health institutions. It indicated that 9.5 M x-ray examinations (5.5 M medical and 4.0 M dental) were performed annually in Switzerland, leading to an annual collective dose to the population of 7,100 Sv and an average annual effective dose of 1.0 mSv/person.

Diagnostic and interventional radiology registers changes in the techniques: (a) a generalized use of higher sensitivity for conventional image receptors (i.e., non digital); (b) an increase of interventional procedures in number and complexity; (c) a spread of the CT multislice technique; and (d) an increased use of digital radiography. It also registers changes because the increasing concern of the personnel in diagnostic and interventional radiology (international recommendations, national regulations) to better manage radiation doses has resulted in significant changes in the protocols and procedures related to many types of examinations, particularly dose-intensive ones (CT, interventional) (ICRP

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2002; McNitt-Gray 2002; Mayo et al. 2003; Brenner and Elliston 2004; Kalra et al. 2004; Spelic et al. 2004; ICRP 2004; Gray et al. 2005).

In the recommendations of the final report (Aroua et al. 2000) of the Swiss 1998 survey, concerning the updating of the data it was stated that given the rate at which radiodiagnostics evolve and are implemented practically, "two types of updating are necessary: an updating survey every 5 years; and a re-evaluation survey every 20 years." It was recommended that "the five-year updating of the annual frequencies of examinations could be done as a mini-survey targeting a population with a size close to 10% of the one used in this survey. It should concentrate on big-size hospitals (> 500 beds), where the most intensive examinations take place, and a small number of medium- and small-size hospitals, radiology institutes and surgeries which are well distributed geographically."

In the course of 2004, an updating study was organized to monitor the frequencies of x-ray examinations carried out in 2003 (five years after the 1998 investigation). This paper describes the methodology of the survey and presents and discusses the main results obtained.

METHOD

The survey covered a sample of 30 hospitals, 10 radiologists, and 206 general practitioners (GPs). The GP sample was stratified on the seven Swiss geographic regions. Half of the GP sample consisted of assiduous and conscientious participants to the 1998 survey, i.e., those who provided detailed and well presented information, and the other half consisted of randomly selected GPs from the 1998 database, in order to examine potential bias. A questionnaire was sent to the GPs with a list of the 30 x-ray examinations most commonly used in general practice in Switzerland. The GPs were asked to give the annual number of examinations they performed during 2003 for each type of x-ray examination, which is to be compared to the 1998 data. The GPs were also asked to indicate the screen-film speed class used for the various types of x-ray examinations. Five categories of x-ray examinations were considered: skull; chest; spine and abdomen; hip, knee and shoulder; and limbs.

The sample of hospitals consisted of 10 large ones (with more than 500 beds) and 20 medium and small ones (with less than 500 beds). This represents about 10% of the total number of hospitals in Switzerland, but in terms of the associated number of beds, it represents more than 25% of the total number. The heads of the radiology departments of the contacted hospitals were asked to give the annual number of x-ray examinations they performed during 2003, by type of examination and/or radiological modality. The collected data are compared to the data of the 1998 survey.

Concerning the dosimetric follow up, the evaluation focused on the most irradiating types of examinations in terms of the collective dose, i.e.:

1. high-frequency examinations (radiography). For this category of conventional examinations, it is assumed that the technical parameters (kV, mAs, numbers of projections) have not changed during a 5-y period. Therefore, only the data collected during the updating survey concerning the screen-film sensitivity are used in the dose evaluation. The impact of digital radiography has not been taken into account for two reasons. First of all, the use of this technology is not common among GPs. Secondly, if these systems once had a lower sensitivity than screen-film systems, many efforts have been done to solve that problem over time. This aspect could be studied separately; and
2. high-dose examinations (CT and fluoroscopy). For this category of complex examinations, it is likely that the protocols and procedures have changed. Therefore, the results of other surveys conducted in 2002 and 2003 specific to CT, fluoroscopy, and cardiology (Aroua et al. 2003, 2004a and b) are used.

RESULTS

Among the 206 solicited GPs, 154 responded favorably (75%). If the 18 "end of carriers" are ignored (retirements and deaths), then the effective response rate obtained amounts to 82%. The response rates for the sample of the "1998 good participants" and the "random sample" are 77.7% and 71.8%, respectively. Of the sample of 10 radiologists solicited only two responded favorably (20% response rate); their data are hence ignored. Concerning the hospitals, half of the total number responded favorably; this represents 59% in terms of number of beds.

Fig. 1 shows the frequency results obtained for the GPs. They are expressed in terms of the total annual number of x-ray examinations performed by all the respondents, and in terms of the average annual number of x-ray examinations per GP. A total number of 71,276 x-ray examinations were registered for 154 respondents, leading to an average annual number of 463 x-ray examinations per GP (between 430 and 494 for the two partial samples).

Table 1 presents the annual number of examinations performed by the 15 hospitals in 2003 and compares it to the 1998 data. A total of 743,277 examinations were registered—an average of 49,552 examinations per hospital.

Table 2 presents the results obtained for the sensitivity class of the film-screen combinations (*S*) used by

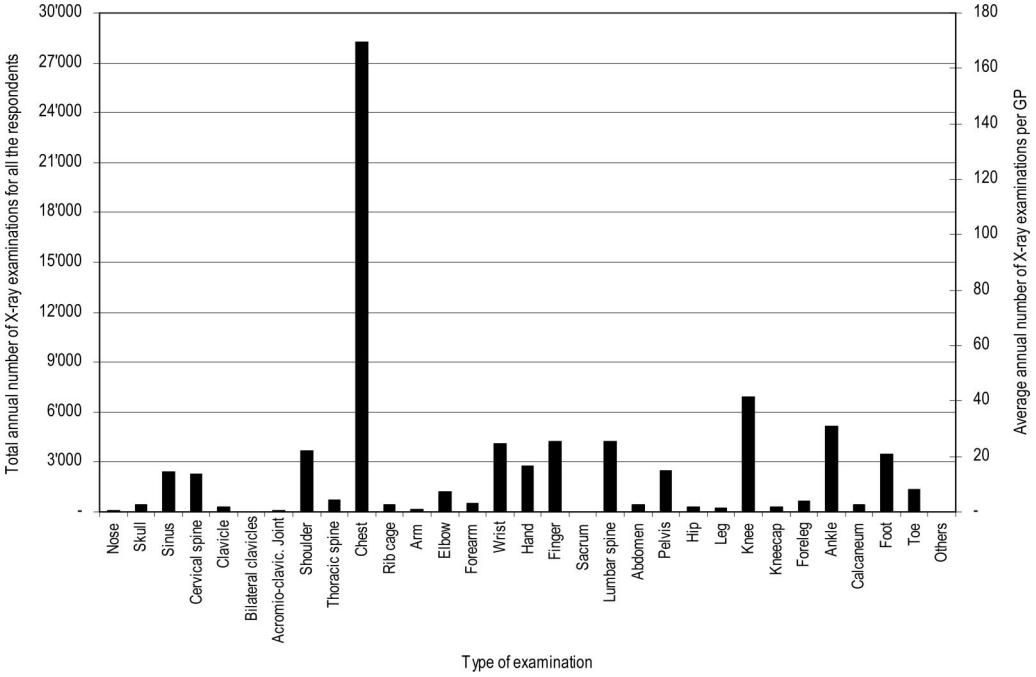

Fig. 1. Frequency results collected from the respondent GPs.

Table 1. Variation of the total number of x-ray examinations in the 15 responding hospitals.

Radiological modality	Number of examinations		Ratio 2003/1998
	1998	2003	
Radiography	551,525	559,718	1.01
Conventional fluoroscopy	25,643	14,252	0.56
Computed tomography	73,379	121,620	1.66
Angiography	22,028	12,419	0.56
Interventional radiology	12,476	9,719	0.78
All	711,348	743,277	1.04

GPs. For each category of examinations, the percentage of use of each class of sensitivity is shown. The *S* values recommended in Switzerland (SFOPH 2001) are also given. Table 2 presents also the overall decrease in dose in 2003 compared to 1998 due to the use of higher sensitivities of the film-screen combinations.

The dose variation for fluoroscopy examinations is measured by considering a sample of 11 types of examinations covering all modalities involving fluoroscopy (conventional, angiography, interventional). The results of two separate surveys on fluoroscopic examinations are used (Aroua et al. 2004a and b). Table 3 compares for these types of examinations the kerma-area products (KAP) measured during the 2003 surveys with the figures established by calculation during the 1998 survey.

In a recent study (Aroua et al. 2003) the protocols used in CT in the Swiss hospitals were investigated. The dose-length products (DLP) established in this study were compared to those obtained during the 1998 survey. Table 4 summarizes the results of this comparison.

DISCUSSION

Frequency of examination

During the 1998 survey, the same sample of 154 GPs considered in the present investigation performed 71,850 x-ray examinations per year (466 per GP), leading to a 2003/1998 ratio of 0.992. The 5-y frequency variation in terms of the total number of all types of x-ray examinations is therefore less than 1% (within 10% for the two partial samples). More than a third of the total number of radiographies performed by GPs (36.6%) are related to chest radiography with 169 examinations per GP per year (Fig. 1). The five other most frequent examinations (more than 5% contribution) are radiographies of the knee (8.9%), the ankle (6.7%), the lumbar spine (5.5%), the finger (5.5%), and the wrist (5.3%). Fig. 2 gives a comparison between the frequency results obtained in this survey and those obtained during the 1998 survey. The ratio of the two sets of data is presented. The types of x-ray examinations are sorted by deceasing frequency. Fig. 2 shows that the 2003/1998 ratio for the 30 types of x-ray examinations considered separately displays some variations although the ratio of the total number equals almost one.

Concerning the hospitals, the comparison with the 1998 data provided by the same 15 hospitals shows an overall increase of 4% (all modalities together). If the main

Table 2. Sensitivity of the film-screen combination, *S*, and the ratio of the doses delivered by a GP in 2003 and 1998 (R03/98).

X-ray examination	S100 (%)	S200 (%)	S400 (%)	S800 (%)	Other (%)	Recommended *S*	R03/98
Skull	11.8	71.4	13.4	0.8	2.5	200–400	0.86
Chest	6.5	69.6	18.1	0.7	5.1	400	0.84
Spine, abdomen	6.8	19.6	23.6	40.5	9.5	400–800	0.78
Hip, knee, shoulder	12.4	66.0	15.0	3.3	3.3	400	0.74
Limbs	31.8	51.6	9.6	3.8	3.2	200–400	0.84
All examinations	—	—	—	—	—	—	0.82

Table 3. Comparison of the 2003 and 1998 average values of the fluoroscopy duration, *T* (s), the number of images, *N*, and the KAP (Gy cm^{-2}).

	T		*N*		KAP		
Type of examination	1998	2003	1998	2003	1998	2003	2003/1998
Barium meal	1,260	355	18	44	105	67	0.64
Lower limb angiography	300	395	90	126	35	178	5.09
Cerebral angiography	300	754	250	679	24	121	5.04
Barium enema	240	470	10	17	37	114	3.08
Hepatic embolisation	1,500	1,321	200	140	240	463	1.93
Biliary drainage and stenting	1,200	1,267	20	31	110	244	2.22
Cerebral embolisation	1,800	2,191	200	760	31	335	10.8
Iliac dilatation and stenting	300	1,149	50	158	43	344	8.00
Coronarography	240	343	500	1,060	27	57	2.11
PTCA	600	904	500	1,238	33	82	2.48
Thermo-ablation	3,000	1,323	200	0	96	128	1.33

Table 4. Dose-length product (DLP) variation for common CT examinations.

Part of the body	Contribution to the total number	$F_{conversion}$ (mSv/Gy cm^{-1})	Average DLP (mGy cm^{-1})		
			1998	2003	2003/1998
Head	38.2%	2.8	970	1,250	1.29
Chest	16.2%	16	590	370	0.63
Abdomen	45.6%	18	580	790	1.33

radiological modalities are considered specifically, for radiography a 1% increase of the number of radiographies is registered, even if the frequency variation of some examinations is higher (skeleton: 4% decrease, chest: 5% decrease, abdomen: 2% increase, and mammography: 19% increase). For fluoroscopy examinations a 44% decrease is registered. There is a 56% decrease for intravenous urography (IVU), a 5% decrease for barium meal, and a 71% decrease for barium enema. The overall decrease of angiographies amounts to 44%, and that of interventional procedures amounts to 22% when all 15 hospitals are considered. If both modalities are put together, then the overall decrease amounts to 36%. The decrease of barium meals might be due to the replacement of this technique by endoscopy, while the decrease of IVUs, barium enemas, and angiographies can be explained by the fact that such investigations are more and more performed with CT. In fact, a clear increase of the number of CT procedures is registered for almost all the hospitals. The overall increase amounts to 66%. CT examinations of the skull, chest, and abdomen show the same 80% increase. The increase in the use of CT was registered in several countries. In Germany the increase in the collective dose due to CT increased by about 50% between 1996 and 2002.[§] The frequency of CT examinations increased in Norway by a factor 2.7 between 1983 and 2002,** and by 39% in the UK between 1998 and 2002.[††]

Dose per examination

Table 2 shows that the GPs are still not fully complying with the recommendations of the radiation protection authority. For skull radiography, in 11.8% of the cases the film-screen sensitivity used is below class S200. The

[§] Personal communication, E. Nekolla, R. Veit, and J. Griebel, German Federal Office for Radiation Protection; 2005.

** Personal communication, I. Borretzen, K. Bakke, and H. Olerud, Norwegian Radiation Protection Authority; 2005.

[††] Personal communication, D. Hart, UK Health Protection Agency; 2005.

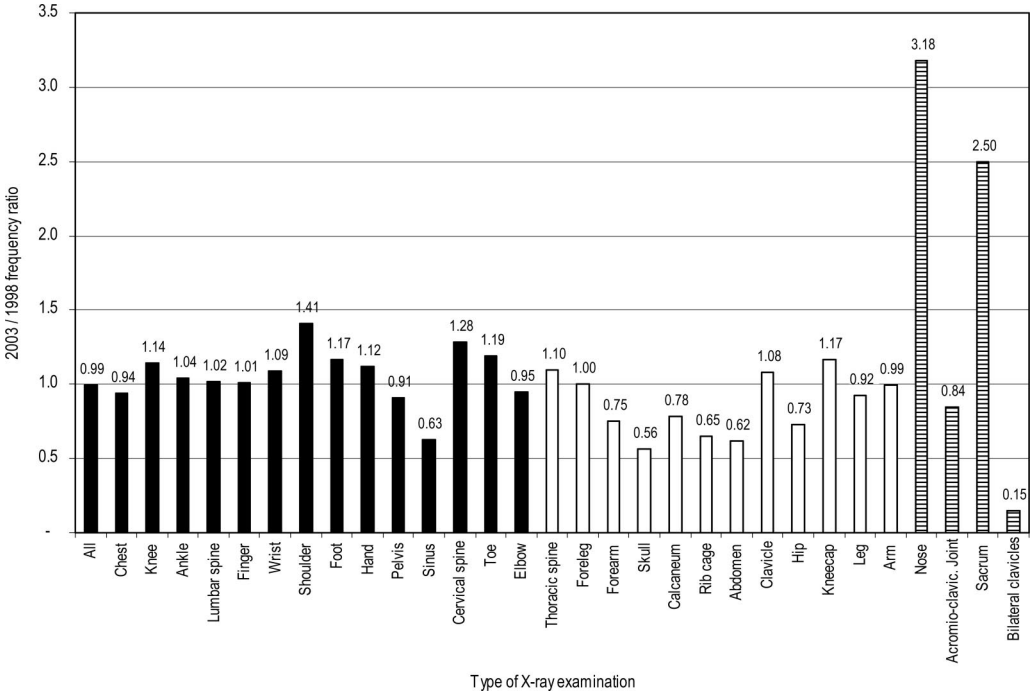

Fig. 2. Comparison of the frequencies of x-ray examinations related to GPs obtained during the 1998 and the 2003 surveys. The examinations are sorted by decreasing frequency. Three zones are shown. In black: the total number of examinations *N* above 1,000; in white: *N* between 1,000 and 100; and in dashed: *N* below 100.

fraction of sensitivities lower than the recommended value reaches 76.1% for chest radiography, 26.4% for the "spine-abdomen" category, 78.4% for the "hip-knee-shoulder" category, and 31.8% for the limbs. The results obtained in this study concerning the film-screen sensitivities used by the GPs were compared to the results obtained during the 1998 survey. A significant shift is registered during the period 1998–2003 towards higher sensitivities. Table 2 shows that the overall gain in dose efficiency in 2003 compared to 1998 due to the use of higher sensitivities of the film-screen combinations is between 26% for the "hip-knee-shoulder" category to 14% for the skull. If all the radiographies are considered, taking into account their relative frequencies, then the total dose delivered by a GP in 2003 would be 18% lower than that delivered in 1998.

Concerning fluoroscopy examinations, a significant increase of the dose per examination is registered for most examinations. In the case of iliac dilatation and stenting there is an increase of almost one order of magnitude. If all the 11 examinations are considered, taking into account their relative frequencies and doses, then the overall change in the effective dose is an increase by a factor of 1.66. The large KAP differences can be explained by larges differences in the technical parameters of the examinations (*T*: fluoroscopy times, *N*: number of frames) as shown in Table 3. When comparing the 1998 and 2003 KAP figures one should keep in mind the two sets of data were established by two different methods. In 1998 typical technical parameters (kV, fluoroscopy time, number of images, etc.) were assigned to each type of examination and validated in practices and hospitals at the national level. From the technical parameters the KAP was calculated using an appropriate dosimetric model, whereas in 2003 the KAP was measured on patients for each examination during a survey that covered the Swiss university hospitals. The differences between the 1998 and the 2003 KAP values (an overall increase) may be due to three reasons: 1) the typical technical parameters validated in 1998 may have been somehow optimistic corresponding to idealistic cases; 2) the KAPs measured in 2003 are specific to university hospitals where the concentration of "heavy" cases (complex procedures) and the training of young radiologists may result in longer fluoroscopy times and higher numbers of images; and 3) the technique (the protocol of the examination) may have changed in a 5-y period.

The decrease of the KAP for barium meal from 1998 to 2003 can be explained by the fact that the fluoroscopy time was overestimated in 1998. The value obtained in 2003 appears to be more realistic when compared with international data (Veit and Bauer 2004). The large increase in KAP concerning lower limb angiography cannot be explained only by differences in the fluoroscopy time and the number of images. The main problem for this examination is that usually the lower limb is not only fully covered but

the field of view extends outside the explored area; the KAP measured is therefore not representative of the dose received by the patient. Moreover, it is not absolutely sure that radiologists systematically adapted the size of the x-ray beam to the examined area. The KAP used in 1998 appears to be small in comparison to data published in the literature (86–101 Gy cm^{-2}) (Brambilla et al. 2004), but it is in good agreement with data previously published by Ruiz Cruces et al. (1998) (30 Gy cm^{-2}). For iliac dilatation and stenting, the fluoroscopy time and the number of images seem to have been underestimated in 1998. In the literature, values in the range of 206–300 Gy cm^{-2} are mentioned for this examination (Miller et al. 2003), which are more compatible with the result of the 2003 survey. The same comment holds for cerebral examinations (angiography and embolization), where the KAPs obtained in 2003 are compatible with data available in the literature (Brambilla et al. 2004; Ruiz Cruces et al. 1998), as well as barium enema, coronarography, and percutaneous coronary angioplasty (PTCA). For hepatic embolization and biliary drainage, the range of variation is so wide that the difference obtained is not significant.

As regards the dose per CT procedure, Table 4 shows that the DLP-2003 to DLP-1998 ratio ranges from 0.63 to 1.33. If all categories of examinations are considered, taking into account their relative frequencies and doses, then the overall change in the effective dose is an increase by a factor 1.2. The increase in DLP registered for CT examinations of the head when comparing the protocols used in 1998 and 2003 is mainly due to the fact that technological progresses (higher temporal and spatial resolution improvement, multi-slice technology) allow for new kinds of investigations. In addition to standard brain CT, head angiographies are now used in routine. A supplementary phase is often added to the native and the injected phases such as a perfusion sequence or a phase for imaging the circle of Willis. This leads to an increase in diagnostic information, but also an increase in patient dose. The decrease of dose for chest CT is due to the fact that the radiologists have been convinced that in the lung area one could significantly decrease the dose without noticeable loss of diagnostic information. Finally, concerning abdomen CT, as for brain examinations, the progress of technology has allowed acquiring longer body lengths at different contrast phases that leads to an increase of the DLP parameter.

Collective dose

Table 5 presents the contribution of each of the three main radiological modalities to the collective dose and the change of the frequency, the dose per examination and the collective dose due to each modality for the period 1998–2003. The three specific variations result in an overall increase of the total collective dose by a factor of 1.2. This means that in 2003 the annual effective dose per caput in Switzerland due to radiodiagnostics was 1.2 mSv.

CONCLUSION

This study allowed updating the 1998 nationwide survey on the exposure of the population by medical x-ray imaging. It allowed surveying the situation of radiography in the medical general practice and investigating its evolution during a 5-y period (1998–2003). The survey addressed 206 GPs of which 154 responded favorably and provided their 2003 frequency data as well as information on the sensitivities of film-screen combinations they use. The study indicated that, in terms of total number of all x-ray examinations, there was only a 1% decrease between 1998 and 2003. The sensitivities of the film-screen combinations registered a shift towards higher values but are still not fully complying with the official recommendations, particularly for chest, hip, knee, and shoulder radiographies. If the frequency variations, the effective doses of the various types of x-ray examinations, and the dose reduction due to the shift in sensitivities of the film-screen combinations are considered, then the reduction registered between 1998 and 2003 of the dose delivered by a GP is of the order of 20%.

This study also allowed the surveying of the situation of diagnostic and interventional radiology in the Swiss hospitals and investigating their evolution from 1998 to 2003. The survey addressed 30 hospitals of which 15 responded favorably and provided their 2003 frequency data. The study indicated that in terms of total number of all x-ray examinations there was only a 4% increase between 1997 and 2003, and that the total

Table 5. Summary of change of the frequency, the dose per examination and the collective dose for the period 1998–2003.

Radiological modality	Contribution to the collective dose	Change in the		
		frequency	dose/examination	collective dose
Radiography	41.2%	1.00	0.82	0.82
Fluoroscopy	28.6%	0.61	1.66	1.01
CT	27.8%	1.66	1.20	1.99

number of radiographies performed in hospitals registered a 1% increase only during this period. However, the other radiological modalities registered significant frequency changes: 39% decrease for examinations involving fluoroscopy, and 70% increase for CT examinations.

Concerning the doses, the investigation of a selection of examinations involving fluoroscopy showed a significant increase of the KAP per procedure. For CT the study showed an increase of the DLP per procedure for skull and abdomen examinations, and a decrease for chest examination. The frequency and dose increase in CT can be explained by the introduction of multi-slice CT, which opened a new field of vascular investigations that used to be performed by fluoroscopic angiography. This may also partly explain the reduction of the number of fluoroscopic examinations.

When both the frequency variation and the change in the effective dose are considered, the change in the total collective dose is then found to be a 20% increase. This means that in Switzerland the average effective dose in 2003 was 1.2 mSv per person, per year. This increase is due mainly to the significant increase in the frequency of CT examinations, and to a lesser extent to higher doses per procedures in CT and fluoroscopy.

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